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TACTILE SATELLITE NAVIGATION SYSTEM: USING HAPTIC TECHNOLOGY TO ENHANCE THE SENSE OF ORIENTATION AND DIRECTION

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The majority of commercially available navigations systems use visual or acoustic instructions to indicate the path from a chosen starting point to a pre-defined destination. Alternatively, several haptic devices and concepts which enhance the sense of orientation and direction have been proposed. A haptic device uses mechanical vibration to stimulate the touch receptors in the skin. It can give navigation information by activating tactile actuators (e.g. vibration motors) indicating the direction of the destination. The direct input from such a device allows a faster response time than watching and interpreting a screen or listening to the information. By not distracting other senses, this approach helps the user to focus on other simultaneous tasks which require senses like vision and hearing. Hence individuals with impaired vision or hearing can benefit from this approach. Another application of the device is the usage as an additional help for orientation that is indicating cardinal direction or the direction to a specified location, like someone's home. New environments to the wearer can be explored more intuitively by using this extra sense of orientation. The system can be integrated in wearable electronics e.g. a waist belt. In this work a prototype of a tactile satellite navigation system was developed. The system consists of a Galileo-compatible Global Navigation Satellite System (GNSS) receiver and an array of several tactile actuators for the transmission of haptic information. Preliminary test results with the system are discussed. Further possible applications to explore the potential of such systems are evaluated, reaching from implementations for private as well as professional use. The usage for individuals with impaired vision or hearing is promising as the haptic device becomes like a "6th sense" allowing the individual to compensate for sensory impairments.

Keywords: Haptic technology, tactile satellite navigation system, navigation belt

I. INTRODUCTION

Nowadays, GNSS based navigation systems are used in all aspects of people's everyday activities. They serve not only to provide driving instructions, but also for biking, hiking, geocaching, walking in unknown cities and areas. Despite the popularity of navigation systems, the commercially available navigation devices are either visual or audio based, which might not be optimal for every user group or application because they require audio-visual attention and manipulation with the hands. For instance, geocachers use their hands and eyes to look for the hidden cache and at the same time they do not want to make this search obvious to other people. In the case of cyclists and motorcyclists, they need to concentrate on the road instead of navigation to avoid accidents. Also runners might not like to waste time determining directions from the device screen. Another group of people, like visually impaired people or patients with Alzheimer's disease, may not be able to use the visual information and constant audio directions might be too distracting for them or unclear in noisy environments. Ongoing research in the tourism sector indicates that most people do not like to make it obvious that they are using navigation by looking at a map or a screen.[1, 2] Instead they want to focus on the attractions and sightseeing while being naturally integrated in the environment.

The solution for such user groups and applications is a wearable tactile navigation system. These systems have been subject of a few research and independent projects. Several studies point out that tactile feedback allows people to navigate and perform better than with a paper map or verbal instructions. Further a tactile navigation system provides the sense of direction in a natural, easily usable and discrete form, without audio-visual distraction for the user by allowing the

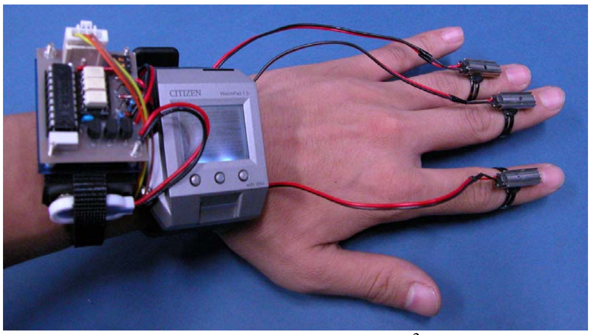

Fig. 1: Tactile glove by Amemiya et al.[3]

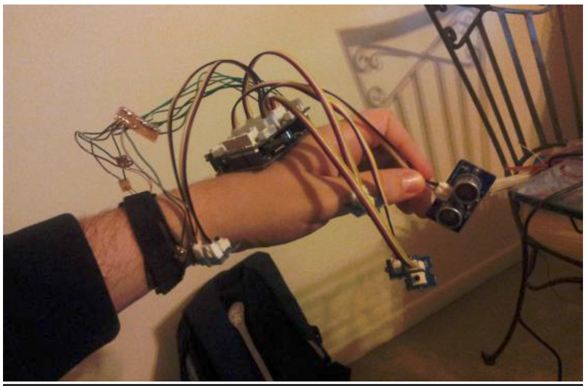

Fig. 2: Tactile device with ultrasonic sensors by Keyes et al.[4]

development of a new 6th sense via vibrotactile stimulation.

This work gives an overview about current tactile navigation systems in the next chapter and then presents a new tactile navigation system in chapter III. In chapter IV several use cases for tactile navigation are discussed. The work is concluded in chapter V.

II. PREVIOUS WORK

Several forms of tactile navigation systems were studied. The following sections present those systems with a focus on tactile navigation belts.

II.I. Tactile Navigation Gloves

Amemiya et al. [3] proposed haptic gloves for the deaf-blind. The navigation system consists of a wearable interface for Finger-Braille for both hands. Two wrist watches on each hand were used to inform the user of their direction (see Fig. 1). The user position was obtained by triangulation of RFID tags.

A more recent approach was presented by Keyes et al.[4] The prototype is a haptic feedback glove able to detect near obstacles using ultrasonic sensors. Then, its vibration intensity is adjusted according to the object distance. The user can select the next destination of a predefined path by pushing a button. Although it could be a promising approach, the prototype seems to be in an early stage of development (see Fig. 2).

The general disadvantage of such approaches is that the finger movement and sensitivity become limited by the gloves which might not be ideal for tasks that require the use of the hands.

II.II. Tactile Navigation Bracelets

Bosman et al.[5] used two wristbands to indicate the direction via a tactile stimulus where test participants had to follow a track with several changes of direction. The device consists of two units that are attached to the wrists, which can wirelessly receive directional information from a control unit. (Fig. 3). Left and right are indicated via vibration on the right wrist and on the left wrist.

Another system with two bracelets on each hand was proposed by Kammoun et al.[6] where it was found that two bracelets are a solution with less cognitive load to

Fig. 3: Navigation bracelets on the left and right hand as used by S. Bosman et al.[5]

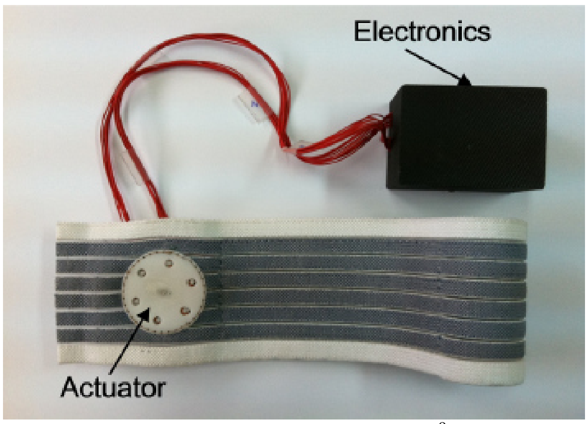

Fig. 4: Bracelet designed by Paneels et al.[9]

Fig. 5: Navigation wrist band by the German Aerospace Centre (DLR)[10]

the user than one bracelet. The same concept with two bracelets is used by CreAppTec GmbH with their upcoming product VibyGo.[7]

A vibrotactile bracelet for blind people was developed by Gelmuda et al.[8]. Their device has six vibration motors and can inform a blind person by giving directional information.

A similar approach with also six motors (see Fig. 4) was presented by Paneels et al.[9] in which they experiment with different vibration patterns to navigate (left, right, back and front) and to identify points of interests (e.g. stairs, toilets or emergency exit). An experimental study with 40 participants determines that it is difficult to distinguish between the vibration patterns in such a small device.

Also the DLR (German Aerospace Center) developed a bracelet for navigation which is called VibroTac[10] (Fig. 5). The device is wirelessly connected with a control unit that gives the commands to the bracelet. The bracelet itself has six vibration motors integrated which are placed around the wrist or arm.

The reviewed works show that approaches with a single bracelet is not enough for determining directions. Dual bracelets approaches seem more promising. However, the existing prototypes have still bulky design or are in a preliminary stage.

II.III. Tactile Navigation Helmet and Bicycle Handles

A combined visual-haptic navigation system for cyclists was presented by Poppinga et al.[11] The system called Tacticycle is composed of a GNSS-enabled smartphone and two vibration actuators on bicycle handles (see Fig. 6). A route is displayed on the smartphone screen while the actuators vibrate to indicate the direction in which cyclist must turn. A field study conducted with 11 participants concludes that cyclists feel oriented thanks to the turn-by-turn vibration cues rather than using the visual display which was difficult to read under sunshine or the rain.

A rather creative and painful concept of a tactile helmet was developed by Kojima et al.[12] (see Fig. 7).

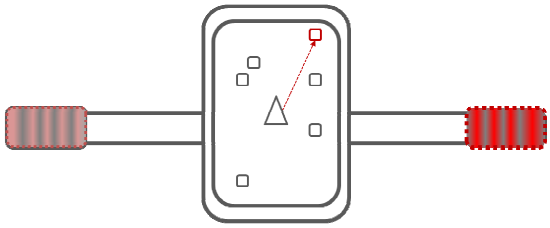

Fig. 6: Handle bar with smartphone attached that displays the route when navigating on a bicycle. The handle bar vibrates to indicate a right turn. [11]

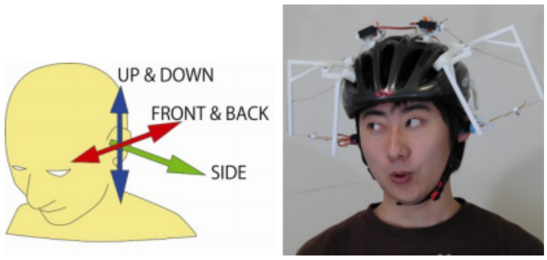

Fig. 7: Navigation by ear pulling as proposed by Kojima et al.[12] showing the 3-dimensional approach (left) and the device (right).

They use a rubber band attached to the wearer's ear and the direction can be indicated by pulling the left or right ear in the desired direction. Tests were also done for indicating up and down.

II.IV. Tactile Navigation Harness

Another form of tactile display is a harness or vest. Dharma et al.[13] presented a wearable haptic vest that can display feedback patterns with 60 actuators to the skin around the torso. They found that the back is the best place to sense the vibration patterns (Fig. 8).

A similar device with 16 vibration motors was tested by Ertan et al.[14] to deliver haptic navigational signals to the user's back, like locating a person, but also using it for route planning. User testing was conducted to evaluate the effectiveness of this system as a navigation guide for sighted users in an unfamiliar area.

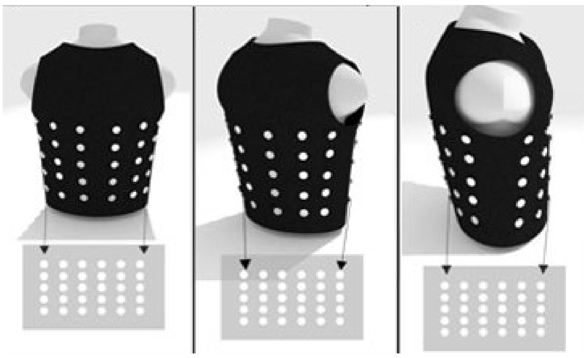

Fig. 8: Navigation vest with 60 actuators around the torso presented by Dharma et al.[13]

Further tests will address the issues of blind navigation. User location is detected by using several infrared sensors around the environment.

II.V. Tactile Navigation Belts

A widely researched device for tactile navigation is a belt or waistband. While several concepts exist, there is no agreement in the amount of vibration motors that is needed to differentiate between directions. As shown by Heuten et al.[15] even six vibration motors placed along the axis of the belt allow the users to recognize directions comfortably.

Tsukada et al.[16] presented a device consisting of a direction sensor, a GPS sensor, multiple vibration motors and a microcontroller (see Fig. 9). The coordinates of the target destination, in form of latitude and longitude, can be sent to the belt from an external device, e.g. a smartphone. The pulse interval of the belt becomes shorter when the user comes nearer to the destination. The system is also proposed to indicate locations of interest, e.g. restaurants or shops with a suitable app on the mobile phone.

Erp et al. [17] studied the use of a vibrotractile belt with eight vibration motors for the use in a military operations such as a helicopter flight. They used different vibration schemes to indicate the distance to the destination but found that there is no significant impact in the scheme to improve walking speed.

Nagel et al. studied the integration of tactile direction signals and found that they can be learned, integrated into behaviour and that they affect perceptual experience[18]. The same research group later developed a navigation belt together with the company feelSpace. Their current prototype consists of several vibration motors (see Fig. 10). The belt can navigate the user to a specific destination that was previously set.

Seltenpohl and Bouwer[19] developed a vibration belt with eight vibration motors aimed at cyclist navigation. The navigational information is provided by a smartphone which is connected via USB to the belt (Fig. 11). Different vibration patterns indicate waypoints (turning information) and endpoint (the final destination).

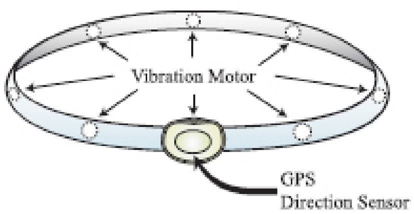

Fig. 9: Basic concept of the ActiveBelt as tested by Tsukada et al. [16]

Fig. 10: Navigation belt by feelSpace[18]

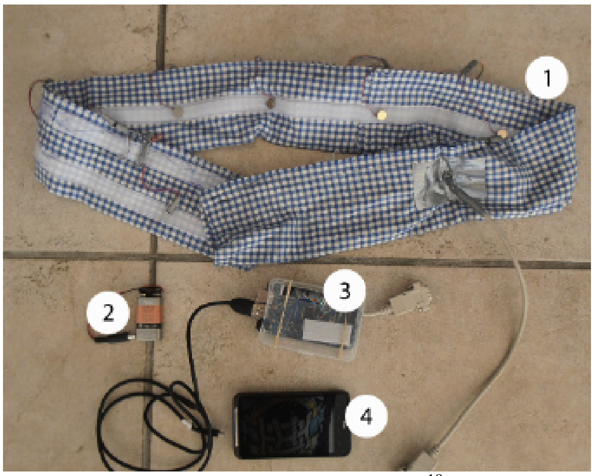

Fig. 11: Tactile belt by Seltenpohl et al.[19] with belt (1), battery (2), control unit (3) and smartphone (4)

Tests were conducted with 20 cyclists who reported easier navigation with the belt as compared to visual aid. However endpoint indication was confusing.

Duistermaat et al.[20] performed a study on the usefulness of tactile navigation belt for military purposes in the US army. For the experiments vibration belt with eight vibrations was used. The hardware consisted of power pack and microprocessor in the backpack and a control unit in the pocket, connected by cables. The setup also included an electronic compass. Different patterns indicating direction, being close to the destination, arriving at the destination, being in or out of the of-limits areas were employed. A number of experiments, including many types of paths and obstacles, found that tactile navigation was more useful than the navigation with visual or head-mounted display.

A tactile belt with seven vibration motor was used by McDaniel et al. [21] to assist individuals who are blind or visually impaired by detecting position and distance of other people (Fig. 12). Experiments were made to compare the discrete vibration feedback (one motor at a time only) versus interpolating the vibration feedback between two motors when the direction falls to the

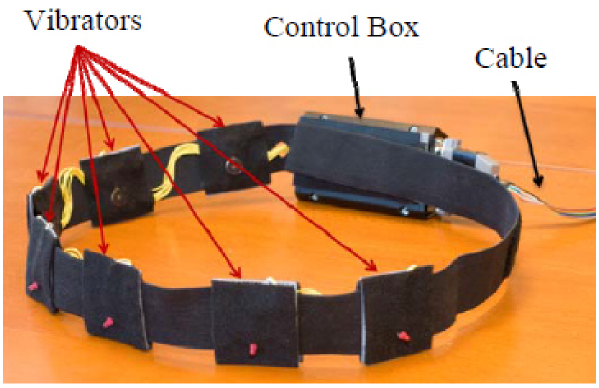

Fig. 12: Tactile belt with 7 vibration motors by McDaniel et al.[21]

range between these two.

Pielot et al.[22] used a belt with six vibration motors. Experiments with 15 people show that the interpolated direction presentation improves the accuracy of perceived directions. Discrete direction presentation (one motor at a time only), was better suited for waypoint navigation and appeared to be easier and faster to process.

Results of Srikulwong and O'Neill's [23] experiments with using belt based navigation and comparing it to smartphone navigation are consistent with most of the findings in this field of research. Authors were using a belt with eight motors. They report that the navigation is as accurate as smartphone based visual navigation and is much faster. An error of 45 degrees between actual and perceived direction was systematically reported, which could be explained by findings of Van Erp's [24] that the directions were perceived with a bias towards the middle of the body (navel or spine). Authors used straight signal as confirmation and notified when the destination was reached by vibrating all the actuators simultaneously. Their prototype required a backpack with a computer. Several reported minor incidents when users were constantly looking at the mobile phone was another disadvantage of smartphone based navigation.

The company Elitac developed together with the Royal Netherlands Army a Mission Navigation Belt for military operations.[25] Their system can be used to transmit information regarding navigation, communication, and warning signals.

III. TACTILE SATELLITE NAVIGATION SYSTEM PROTOTYPE

III.I. Tactile Navigation Belt

Our system (see Fig. 13) consists of three parts: 1) a smartphone app, which connects to GNSS to obtain the position of the user; 2) a vibrotactile feedback device, which informs the user about the target direction; and 3) a communication protocol for transferring data between the smartphone and feedback device.

III.II. Haptic device

Our haptic device is a waist belt which is equipped with eight vibration motors placed equally apart from each other following the choremes schema[26] and powered by a rechargeable battery. The belt provides tactile navigation via vibrating one or several motors in the needed direction. The intensity and duration of vibrations is changing according to the distance to the next destination point.

Sensovo Vibes is our second prototype (see Fig 14). This belt is made of an elastic fabric that can be easily strapped around the waist and is light and comfortable to wear. A 7x4x2 cm plastic container includes the electronic board and the 3.7 V battery that can holds the charge up to 2 days with a moderate use.

III.III. GNSS-enabled smartphone

Our system utilises a smartphone as a medium to run a navigation application, which allows specifying destinations and using the mobile phone internal GNSS receiver for positioning. Our application is currently available for Android smartphones. The user can select a target destination in three ways: 1) entering geographic coordinates; 2) sharing the location from other applications like Google Maps; and 3) opening a GPX file (an XML format to describe coordinates and routes).

Fig. 13: Proposed system by Sensovo.

Fig. 14: Design of the device.

Then our application communicates via Bluetooth with our wearable accessory which will start vibrating to the desired destination.

If the smartphone is also connected to internet, it is possible to perform an error correction with EGNOS allowing a higher precision of received GPS sensor values. For this purpose the correction values of the EGNOS system or non-commercial internet providers could also be used.

III.IV. Communication protocol

The communication between the wearable device and the smartphone is done point to point using the Bluetooth protocol. Initially both the belt and the smartphone have to be paired. Then, the belt sends a message to the smartphone with basic information like its identifier number and battery charge. Once the belt has been validated by the application, the later will continuously send messages to the belt indicating the bearing and the distance left to the destination. The integrity of all the messages is checked in order to avoid misleading information.

IV. POSSIBLE APPLICATIONS

IV.I. Tourism

The most common map-based forms of navigation for tourists are paper maps and maps on their mobile devices with GPS navigation. The paper maps are not always easy to read and can be less helpful in wayfinding than GPS assisted mobile maps. However it has also been found that the users of GPS directions tend to make more mistakes in navigation than those who use paper maps or directional signs. Moreover, they tend to travel slowly, and pay less attention to the surroundings or landmarks.[27]

Additionally ongoing research in the tourism sector indicates that in many cases tourists prefer to blend in with locals and avoid looking like obvious tourists if possible because of security and cultural reasons.[1, 2] Since constantly checking the map is an indication of being a tourist, the tactile navigation belt can be very useful in this aspect as well. Wearers have to simply input waypoints in the smartphone app before starting sightseeing and begin the navigation. In this way tourists are navigating from one point to another without having to consult a smartphone. Wearing the belt under the clothes or masking it as a normal belt makes the navigation process completely invisible.

IV.II. Geocaching

Geocaching is a modern form of treasure hunting.[28, 29, 30, 31] The members of this community enjoy exploring new environments by seeking little treasures that were hidden by the fellow geocachers. They use their hands and eyes to look for the hidden cache and at the same time they do not want to make this search obvious to other people. Tactile navigation technology can help geocachers to find their treasure without the need of looking on a screen which might be a useful tool to perform the search in the most discreet form possible. At the same time geocachers can be more focused on the environments that they are exploring. [29]

IV.III. Emergency services

The tactile navigation system can be very useful for emergency and rescue services, by allowing the wearer to concentrate fully on the task at hand. Possible scenarios are the use of Sensovo's technology in low visibility environments. This is particularly relevant for applications for fire control when the environment is smoky and vision is decreased, where the low-technology (and sometimes unreliable) navigation methods such as holding the walls, or using lifeline ropes are applied. [32] Other uses may include rescue services during natural cataclysms when the relational navigation may fail due to significant changes in surroundings or in outdoor environment where maps on electronic devices may be difficult to read. Additional functionality - vibrating in the direction of other team members - may be added which can greatly enhance team awareness as well, as shown by Pielot et al. [33]

IV.IV. Traffic and sports

As reported by American National Highway Traffic Safety Administration (NHTSA) 17% of the road accidents happen because of the distractions.[34] In this regard cyclists and motorcyclists are more vulnerable and need to concentrate on the road even more - hence making conventional navigation aids problematic. Tactile navigation can help in this case, by allowing eyes and ears-free navigation. In fact cycling is one of the activities for which the tactile navigation has been considered before.[35]

Another group of users that can benefit from tactile navigation are the runners who might not like to waste time determining directions from the device screen. Other possible applications may be hobby air plane flying, paragliding and horse riding.

IV.V. Impairment

Navigation devices for people with visual impairment are usually audio-based, which can distract the user from environmental sounds which are helpful for orientation. As also considered in several works mentioned above, a tactile navigation device offers the advantage that hearing is not needed and the navigation is purely tactile based.

People with Alzheimer's disease struggle to use conventional navigation devices as understanding maps becomes a difficult task once the spatial orientation decreases.[36, 37]

A tactile device that indicates direction to a person’s home with vibration might well be a considerable option for a more intuitive approach.

V. CONCLUSION

In this work several wearable tactile navigation systems for different parts of human body were reviewed. Most of those devices are in an early stage of development or have a bulky design. We presented a new haptic belt that is lightweight and slim. Thus, a user can freely navigate in connection with our smartphone application which is compatible with existing location-based applications. Several uses cases have been presented in which our system can make a difference in the way of navigation. A pilot study with different groups of people is currently planned. The results will be published in the future.

Tactile navigation has several benefits over conventional navigation systems and should be considered as an alternative to improve awareness of the environment and safety while navigating.

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